

**PIXEL SHIFTING COLOR PROJECTION SYSTEM****CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims the benefit of U.S. Provisional Patent Application Serial  
5 No. 60/511,801 (Atty. Docket No. PU030291), entitled "Pixel Shift Wheel for Displays  
Employing Microdisplays" and filed October 16, 2003; U.S. Provisional Patent Application  
Serial No. 60/511,872 (Atty. Docket No. PU030292), entitled "Resolution Enhanced Dot  
Sequential Display" filed October 16, 2003; and U. S. Provisional Patent Application Serial  
No. 60/511,958 (Atty. Docket No. PU030293), entitled "Minimum Motion Color System for  
10 DLP Like Systems" filed October 16, 2003, which are incorporated by reference herein in  
their entirety.

**FIELD OF THE INVENTION**

The invention is related generally to a projection system, and more particularly to a  
projection system including micro-displays wherein a pattern of discrete color pixels is  
15 shifted.

**BACKGROUND**

Micro-display projection systems using a reflective light engine or imager,  
such as digital light pulse (DLP) imager, are increasingly utilized in color image or video  
20 projection devices (e.g., rear projection television (RPTV)). In an existing projection system,  
shown in Figure 1, a light source 10 is provided, in this case a UHP lamp generates white light  
(i.e., all color spectrums). Light from the light source 10 passes through a color wheel 20  
which has a plurality of dichroic filtering elements, each of which allows a light band of one  
of the colors: blue, green and red to pass through and reflects light of the other colors. The  
25 color wheel 20 is rotated so that a temporal pattern of blue, green, and red light bands pass

through the color wheel. The color wheel is typically rotated fast enough to create at least one primary color period for each primary color during each frame of a video image. Rotating the wheel faster, or using multiple filter segments for one or more of the primary colors can produce color separation artifacts that allow the viewer to detect the sequential color nature of the display system. For example, color breakup, also called the rainbow effect, is caused by light passing through a rotating color wheel with colors flashing sequentially and appears as a momentary flash of rainbow-like striping typically trailing bright objects when looking quickly from one side of a viewing screen to the other, or when quickly looking away from the viewing screen to an off-screen object. Additionally, color edge effects appearing as a flash of one of the three primary colors in the sequential color light beam at a leading edge of a moving object across the screen may also produce color separation artifacts.

An integrator 30 receives the light band from the light source 10 that is allowed to pass through the color wheel 20 and directs the light band through relay optics 40 into a total internal reflection (TIR) prism 50. The TIR prism 50 deflects the light band onto an imager 60, such as a DLP imager. The imager modulates the intensity of individual pixels of the light beam and reflects them back through the TIR prism 50 and into a projection lens system 70. The projection lens system 70 focuses the light pixels onto a screen (not shown) to form a viewable image. A color video image is formed by rapid successive matrices of pixels of each of the three colors (blue, green, and red) which are blended by the viewer's eye to form a full color image.

Throughout this specification, and consistent with the practice of the relevant art, the term pixel is used to designate a small area or dot of an image, the corresponding portion of a light transmission, and the portion of an imager producing that light transmission.

The DLP imager 60 comprises a matrix of micro-mirrors, moveable between an angle that reflects light through the TIR prism 50 and into the projection lens system 70 and an

angle that deflects the light so that it is not projected by the projection lens system 70. Each micro-mirror reflects a pixel of light of a desired intensity depending upon a succession of angles of that particular micro-mirror which in turn are responsive to a video signal addressed to the DLP imager 60. Thus, in the DLP imager 60, each micro-mirror or pixel of the imager modulates the light incident on it according to a gray-scale factor input to the imager or light engine to form a matrix of discrete modulated light signals or pixels.

Existing DLP imagers, however, suffer from several problems. The color wheel wastes light, as the light having the colors that are reflected is typically lost. Also, color separation or break-up artifacts degrade the image quality of the projection system, as described above. Additionally, each micro-mirror may pivot up to twelve times for each of the three color bands for each frame, limiting the frame speed and adversely effecting mechanical reliability. As such, a system for reducing color separation or breakup artifacts and/or having improved resolution and improved reliability is needed.

## SUMMARY

The present invention provides a projection system for projecting a full-color image using a micro-display with reduced mechanical motion and/or increased resolution. In an exemplary embodiment, the projection system has an integrator with an output end having a matrix of output windows therein. An imager modulates the pixels of light. A light shifting device shifts the matrix of pixels of light to temporally form a pattern of overlying monochromatic pixels of light of different colors, viewable as a color image and/or to project pixels of light between the positions of previously projected pixels of light to enhance resolution.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will now be described with reference to the accompanying figures of which:

Figure 1 shows a diagrammatic view of an existing digital light pulse (DLP) projection system;

Figure 2 shows a diagrammatic view of a projection system according to an exemplary embodiment of the invention;

Figure 3 is an end view of the input end of an integrator from the projection system of Figure 2;

Figure 4 is an end view of the output end of the integrator of Figures 2 and 3 showing a pattern of monochromatic filters on output windows of the integrator;

Figure 5 shows an input window of the integrator of Figure 3;

Figure 6 shows a pattern of overlying pixels projected by the projection system of Figure 2;

Figure 7 shows a diagrammatic view of a projection system according to another exemplary embodiment of the invention;

Figure 8 is an end view of the output end of an integrator for the projection system of Figure 7 showing a pattern of monochromatic filters on output windows of the integrator;

Figure 9 is a view of the imager output for the projection system of Figure 7 showing successive color filling;

Figure 10 shows a diagrammatic view of a projection system according to an alternative embodiment of the present invention; and

Figures 11 and 12 are a plan view and side view, respectively, of a pixel shift wheel from the projection system of Figure 10.

**DETAILED DESCRIPTION**

The present invention provides a color projection system, such as for a television display, for projecting a video image with enhanced resolution and/or reduced mechanical motion of the projection system due to shifting of a pattern of monochromatic pixels. In an exemplary embodiment, as shown in Figure 2, white light is generated by a lamp 110 and directed into an integrator 120 by a parabolic reflector 111. In an exemplary embodiment, the lamp 110 is a high intensity multiple wavelength output lamp which is suitable for use in projection display systems. A suitable lamp 110 for this purpose is a UHP lamp that is well known in the art as a light source for projection displays. Light output of the lamp 110 is coupled to an integrator 120. The integrator 120 is formed as a rectangular cylinder for directing light output of the lamp toward an imager 140 in a given rectangular aspect ratio and size which corresponds with that of the imager 140. In this embodiment, the integrator 120 has a peripheral surface 126, which has a reflective coating such as a silver coating extending substantially around its entirety. Referring to Figure 5, the input end 122 of the integrator 120 has a similar reflective coating applied selectively to form a transmissive portion 125 through which light from the lamp passes and a reflective portion 123, which reflects light internally within and along the peripheral surface 126. Similarly, referring to Figure 3 the output end 128 is formed to have a reflective portion 127 and plurality of transmissive portions or windows 123. The windows 123 may be a plurality of apertures through which light is allowed to pass from the interior through the output end 128. Each window 123 has a filter 124 applied thereto for allowing passage of a selected color or band of light while blocking other colors of light from passing therethrough. For example, as shown in Figure 4, filters 124R allows the passage of red light out of the integrator 120 while filters 124B allows passage of blue light out of the integrator 120 and filters 124G allow the passage of green out of the integrator 120. It can be appreciated by those reasonably skilled in the art therefore that

each window 123 may be selected to always transmit the same color light by applying selective filters 124 over selected windows 123. It should be further understood and appreciated that the reflective portions 127 serve to reflect incident light back into the integrator 120 and over the interior surfaces to be eventually redirected once again towards the output end and through windows 123. This serves to conserve illumination and reduce light attenuation through the integrator 120.

As shown in Figure 3, the matrix of output windows 123 are located at the output end 128 of the integrator 120 and arranged in a rectangular grid. Each output window 123 has a monochromatic filter 124 associated with it that transmits a one of the color bands: blue, green and red, while reflecting the other color bands. The monochromatic filters are known in the art, and will not be described herein. The output windows 123 correspond on a one-to-one basis with the micro-mirrors of a DLP imager, which will be described hereafter, and are of a size that is less than or equal to the size of the individual micro-mirrors. Thus, each filtered window passes a pixel of monochromatic light smaller than or equal to the size of an individual micro-mirror.

In an exemplary embodiment, the monochromatic filters 124 are provided in a color pattern, as shown in Figure 4. The first row of output windows 123 have alternating red filters 124R and green filters 124G, that is, filters that pass or transmit only red and green light, respectively. The second row of output windows 123 have alternating green filters 124G and blue filters 124B, that is, filters that pass or transmit only green and blue light, respectively. The third row is the same as the first row; the fourth row is the same as the second row; and so forth. The filters 124 are positioned such that each red filter 24R and each blue filter 124B is horizontally and vertically adjacent green filters 124G.

Referring again to Figure 2, the filtered output windows 123 pass a matrix of monochromatic light pixels of varying colors through a relay optics system 130 and onto an

imager 140. The imager 140 modulates the matrix of monochromatic light pixels on a pixel-by-pixel basis responsive to a video signal addressed to the imager 140. In the embodiment illustrated and described herein, the imager 140 is a digital micro-display (DMD) and more particularly a DLP imager comprising a rectangular grid of micro-mirrors to alternately  
5 deflect the pixel of light incident on the micro-mirror along the projection path or deflect it away from the projection path, depending upon the signal provided for that pixel of the imager. Each micro-mirror is positioned a predetermined number of times (i.e., has a predetermined number of bits in a modulation cycle) to modulate the intensity of that pixel for that frame. The pixel is modulated temporally by the fraction of light that is deflected along  
10 the projection path. For example, a micro-mirror with twelve bits in a modulation cycle will be either on or off each of twelve times (i.e., the micro-mirror will be pivoted to the on position or the off position twelve times). A pixel or micro-mirror that has twelve bits and is on six times will project a pixel of light having half of the maximum intensity. Thus, the imager 140 deflects a matrix of temporally modulated monochromatic pixels of light along the  
15 projection path of a minimum motion projection system.

A relay mirror 150 is positioned in the projection path to reflect the matrix of temporally modulated monochromatic pixels of light into a projection lens system 160, which then projects the pixels of light onto a screen (not shown) to form a viewable image. The relay mirror 150 is configured to pivot over a very small angle to offset the pixels vertically  
20 one pixel location on the screen. Thus, successive pixels of light at a first pixel location are red then, after the matrix is shifted, green. This shift is performed within a single frame, so that the eye blends the two pixels of light together to form a single pixel of light containing both red and green light. When a solid white image is projected, this pixel will be cyan (R/G) as best shown in Figure 6. In the adjacent vertical pixel locations successive green and red  
25 pixels are projected before and after the mirror is shifted, respectively. In horizontally

adjacent pixel locations successive green and blue pixels of light are projected, before and after the mirror is shifted, respectively. Thus, a solid white image will produce alternating columns of cyan (green and red) and yellow (green and blue), as shown in Figure 6, due to the vertical shifting of pixels by mirror 150. Since the columns are a single pixel in width, they  
5 are blended by the eye, and a color image will be projected to produce a full-color image, when adjacent pixels are blended by the eye of a viewer. In this way, the micro-mirrors only need to complete two modulation cycles for each video frame, rather than three, as required to project three different colors on each pixel location. Also, the relay mirror only has to pivot once during a video frame, and a very small adjustment is required to shift the pixels at the  
10 screen. This minimum motion arrangement reduces power consumption and increases reliability and, potentially, the frame speed.

An alternative exemplary embodiment of the present invention is shown in Figure 7. The alternative projection system includes a lamp 110 for transmitting white light being optically coupled to an integrator 120 which outputs light through an imaging lens 130 to a  
15 micro-display 32. Light passes from the micro-display 32 through a shifting plate 34 to a projection lens 160, which outputs images to a screen "not shown". Below, those portions of the system that differ from the previously described embodiment will now be described in greater detail.

The micro-display 32 of this embodiment is a digital light pulse (DLP) micro-display  
20 having a plurality of micromirrors each corresponding to a pixel within the projection system. It should be understood that each window 123 having a filter 29 applied on its output is selected to illuminate a particular micromirror of the micro-display 32 always with the same color light. The micro-display 32 is operated to modulate each pixel with the input video signal as is well known in the art. Pixel output of the micro-display 32 is then passed through  
25 a shifting plate 34. The shifting plate 34 consists of a light transmissive material of a selected



thickness being angularly oriented to the light path and mounted such that it may be pivoted slightly between several output positions. The shifting plate 34 may be pivoted in order to shift the input image a desired amount by refraction, for example one-half or one pixel length on its output. A projection lens 160 receives output from the shifting plate 34 and projects it  
5 onto a screen.

As shown in Figure 8, the filters 29 are arranged sequentially such that a red filter 29R is succeeded along a row by a blue filter 29B and then a green filter 29G. The pattern then continues along that row with red, then blue, then green. It should be understood that the array of Figure 8 is merely illustrative of the sequential nature of the arrangement and that any  
10 size array may be created based on the imager and system requirements. The second row begins with a green filter 29G and then proceeds with the same order of colors that being, red, blue, green. Finally, the third row begins with a blue filter 29B and then follows with the same pattern, that is green, red, blue thus populating the entire array with filters.

In use, the micro-display 32 receives a constant color of light at each respective  
15 micromirror and then modulates each pixel according to the video input signal. Turning now to Figure 9, a succession is shown of the projection lens 160 input 37 during successive modulation intervals. In these drawings, R indicates a red pixel, B indicates a blue pixel, and G indicates a green pixel. After a first modulation interval, the shifting plate 34 is tilted slightly causing the light incident on the projection lens 160 to shift by a selected pitch, which  
20 in this embodiment is two pixel lengths or one micromirror length. In the second modulation interval the pixel positions that had previously been receiving red light will now receive green light and the pixels previously receiving green light will receive blue light. Similarly, those pixels which had been receiving blue light will be receiving red light. In a third modulation time interval the shifting plate 34 is moved once again such that the light shifts another mirror  
25 pitch adding the final primary color to each pixel position. Next, the shifting plate 34 shifts

the image back by one pixel pitch or half a micromirror pitch and the process is repeated adding pixels within same rows in between the first ones that had been previously illuminated with each of the three primary colors. This has advantageous result of displaying every other row of pixels with twice as many pixels per row as there are micromirrors per row. The shifting plate 24 may then be shifted downward by one pixel to fill in between the rows by repeating the previous two process steps.

In another alternate embodiment, the filters may be removed to have the output of the integrator configured as shown in Figure 3 such that the integrator pass all colors of incident light through each window 28 and a color wheel may be added back into the system and located as in Figure 1. In this embodiment, light colors pass sequentially through the integrator 120 according to the position of the color wheel. The micro-display 32 modulates an entire array of each color within a modulation interval and then modulates an entire array of the next successive color in the successive modulation interval and finally the third color in the next successive modulation interval. This results in each pixel defined by the windows 28 of the integrator being successively illuminated with each color to form a full color image without moving the shifting plate 34. The shifting plate 34 is then tilted or moved to fill in additional pixels defined by the reflective portions 27 on the integrator output for improved resolution.

This embodiment advantageously allows an array of micromirrors in a micro-display to sequentially illuminate a relatively larger array on a projection lens thus improving resolution of the system

In yet another alternate embodiment, shown in Figure 10, a projection system includes a lamp 110 for transmitting white light being optically coupled to an integrator 120, which outputs light through an imaging lens array 130 to a TIR prism 31 and onto a micro-display 32. Light passes from the micro-display 32 through the TIR prism 31 to one or more pixel

shift wheels 234 and on to a projection lens 160, which outputs images to a screen (not shown). The unique components of this projection system will now be described in greater detail.

The lamp 110, integrator 120, relay lenses 130, micro-display 32, and projection lenses 160 are the same as is shown in Figure 7 and described above. The TIR prism is similar to the TIR prism shown in Figure 1 and described above.

Instead of a shift plate 34, as shown in Figure 7 and described above, the present embodiment has a shift wheel 234 that functions to shift discrete pixels of monochromatic light by refraction. As shown in Figure 11, the one or more pixel shift wheel 234 comprises one or more refracting segments 52 separated one from the other in an angular direction by one or more non-refracting segments 51. The pixel shift wheel 234 shifts the position of all of the pixels modulated by the micro-display 32 to sequentially position adjacent pixels of other colors onto the same pixel positions in order to get all three primary colors on every pixel position, thereby reducing color separation artifacts.

As shown in Figure 12, the pixel shift wheel 234 rotates on an axis 235 which is not parallel to the light output 237 from the micro-display 32. Instead, the pixel shift wheel 235 is angled with respect to the light output 237, causing the light output to be refracted, shifting the position of each of the pixels in the light output 237. Moreover, the pixel shift wheel 234 shifts the position of all of the pixels by about the same amount and direction depending on the properties of each refracting segment 52. As the pixel shift wheel 234 turns or rotates about axis 235, a different angular segment of the wheel is positioned in the path of the light output 237, producing a different shift direction and/or amount. The amount and or direction of shift depend on the resolution of the one or more refracting segments, through which the light output 237 travels. If the shift takes place at a sufficiently high frequency, the eye will integrate the results from all the shifted pixel positions. A projection lens 160 receives light

output 237 after it has passed through one or more shift wheel 234 and projects it onto a screen (not shown). In addition, the resolution of the displayed image can be enhanced by spatially shifting the pixels to positions between each of the pixel positions for the non-shifted image.

5 In use, the micro-display 32 of Figure 10 receives a constant color of light at each respective micromirror, due to the pattern of filters as shown in Figure 8. The micro-display 32 then modulates each pixel according to the video input signal. Turning now to Figure 9, a succession is shown of the projection lens input (i.e., the light output 237 after passing through the pixel shift wheel 234), during successive modulation intervals. In these drawings, 10 R indicates a red pixel, B indicates a blue pixel, and G indicates a green pixel. When a non-refracting segment 51 is aligned with the light output 237, the individual pixels enter the projection lens, without being shifted. After the non-refracting segment 51, the pixel wheel 234 is rotated so that a first refracting segment 52 is aligned with the light output 237, causing the light incident on the projection lens 160 to shift by a selected pitch, which in this 15 embodiment is two pixel lengths. For the first refracting segment 52, the pixel positions that have previously been receiving red light will now receive green light, and the pixels that have been receiving green light will receive blue light. Similarly, those pixels which have been receiving blue light before the rotation of the pixel shift wheel 234, will be receiving red light. For a second refracting segment 52, different from the first refracting segment, the pixel shift 20 wheel 234 rotates once again such that the light shifts to add the final primary color to each pixel position.

Optionally, a third refracting segment (not shown) on one or more pixel shift wheels 234 shifts the image back by one pixel pitch or about half a micromirror pitch and the process is repeated adding pixels within the same rows between the first ones that had been previously 25 illuminated with each of the three primary colors. This has the advantageous result of

displaying every other row of pixels with twice as many pixels per row as there are micromirrors per row. A fourth refracting segment (not shown) on one or more pixel shift wheels 234 may then be shifted downward by one pixel pitch to fill in between rows by repeating the previous process steps.

5           In an alternative embodiment, the filters may be removed to have the output of the integrator pass all colors of incident light through each window 28 and a color wheel may be added back into the system and located as in Figure 1. In this embodiment, light colors pass sequentially through the integrator 120 according to the position of the color wheel. The micro-display 32 modulates an entire array of one color within a modulation interval and then  
10           modulates an entire array of the next successive color in the succeeding modulation interval, and finally, the third color is modulated in the next modulation interval. This results in each pixel defined by the windows 28 of the integrator 120 being successively illuminated with each color to form a full color image using the one or more pixel shift wheel 234 as described above to improve resolution.

15           The foregoing illustrates some of the possibilities for practicing the invention. Many other embodiments are possible within the scope and spirit of the invention. It is, therefore, intended that the foregoing description be regarded as illustrative rather than limiting, and that the scope of the invention is given by the appended claims together with their full range of equivalents.